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3 December 1953

Report No. 763

Special

Copy No.

INVESTIGATION OF THE GASOLINE AND MIXED FLUORINE-OXYGEN PROPELLANT COMBINATION

Contract N7onr - 462

Task Order No. III

ST. ... INFORMATION

3 December 1953

Report No. 763
(Special)

AN INVESTIGATION OF THE GASOLINE AND MIXED
FLUORINE-OXYGEN PROPELLANT COMBINATION

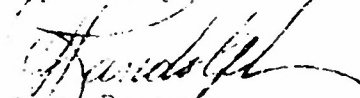
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Task Order III

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AEROJET-GENERAL CORPORATION

Azusa, California

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CONTRACT FULFILLMENT STATEMENT

This special report summarizes the results of one engine test program conducted in partial fulfillment of Contract N7onr-462, Task Order III, Amendment 9.

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I. INTRODUCTION

A. Numerous engine test programs have been conducted by contractors and government agencies in an effort to obtain experimental specific-impulse values of more than 270 lb-sec/lb at 300 psia chamber pressure and an exit pressure of 1 atm, but few propellant combinations have yielded such high values. In practically all instances in which such specific impulses have been recorded, it has been found necessary to use liquid fluorine as the oxidizer (the notable exception being the liquid hydrogen—liquid oxygen combination). Fluorine is quite expensive, with no indication of a major reduction in price in the near future.

B. In February 1952, preliminary results were obtained which indicated that high performance could be obtained by burning gasoline in a rocket engine with a mixture of liquid oxygen and liquid fluorine.* It was recognized from qualitative thermodynamic considerations that the use of a hydrocarbon fuel should make it possible to dilute fluorine with oxygen and still achieve high performance, since the fluorine would preferentially combine with the hydrogen, permitting the oxygen to burn the carbon. A substantial reduction in the amount of fluorine needed, and thus in cost of the oxidizer, would be achieved in this way.

II. OBJECT

It was the purpose of the present test program to investigate further the merit of the hydrocarbon and mixed fluorine-oxygen propellant combination, and to attempt to determine the optimum conditions for high specific impulse without entering into an extensive hardware study.

III. RESUME

Tests made earlier (Ref. 1) and results obtained on the program just completed confirm the original theory. Although a very extensive program would be necessary to determine the optimum fluorine-to-oxygen ratio, over-all oxidizer-to-fuel ratio, injector configuration, and minimum characteristic length of the thrust chamber, a sufficient number of tests have now been made to establish the value of the propellant combination in future considerations of high-energy propellants. With an oxidizer consisting of 67 mole % oxygen (63 wt %) and 33 % fluorine, a maximum specific impulse of 272 lb-sec/lb and a characteristic velocity of 6720 ft/sec have been obtained, comparable with results recently published by NACA (Ref. 2) for ammonia burned with 100% fluorine. Because the NACA discovered that engine configuration had a very important bearing on test results, the performance values reported here with the mixed oxidizer are possibly not the maximum obtainable from the system.

*Equipment under the jurisdiction of this contract was used, but no charges were made to the contract.

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IV. CONCLUSIONS AND RECOMMENDATIONS

If costs of \$0.05/lb are set on ammonia, gasoline, and oxygen, and \$10.00/lb for fluorine, the cost of a pound of propellant necessary to obtain the maximum performance measured in the test program would be \$2.61. The cost per pound of propellant in the NACA ammonia-fluorine tests would be \$7.11 at best. Thus, it is possible to obtain comparable experimental specific impulses with a reduction in costs of almost two-thirds when the mixed oxidizer is used. It is therefore recommended that the gasoline--mixed oxygen and fluorine propellant combination be studied further on a small-thrust scale with respect to injector configurations, and that the ideal engine system then be tested at 3000 to 5000-lb thrust.

V. EQUIPMENT AND INSTRUMENTATION

A. PROPELLANTS

Cylinders containing 6 lb of fluorine each at approximately 360 psi were obtained from the Pennsylvania Salt Manufacturing Company. The gas was used without analysis, previous studies having shown that the purity was normally above 98%. Commercial compressed oxygen was used. The fuel used in this program was aviation gasoline; important specifications of the sample used are as follows:

Carbon, wt %	85.13
Hydrogen, wt %	14.85
Empirical formula	CH ₂ .09
Specific Gravity, $\frac{60^{\circ}\text{F}}{60^{\circ}\text{F}}$	0.697
Bromine number	0.3
Aromatics	0.7%
Vapor pressure (Reid)	6.5 psi
Distillation curve	Initial bp = 107°F 10% 154 50% 212 90% 249 Final bp = 324°F

B. FACILITIES

1. The test facilities are essentially those described in a previous report (Ref.3). A view of the engine and associated equipment is shown in Figure 1. The engine produces 100-lb thrust, and during this test series was operated at an L of 128 in. fuel and oxidizer displacement is accomplished by means of a piston-cylinder system; on the oxidizer side,

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liquid nitrogen within the cylinder displaces the fluorine-oxygen mixture stored within a copper coil surrounded by liquid nitrogen.

2. A single injector was used throughout the series, and because of the widely varying flow conditions it probably was not capable of producing a constant percentage of theoretical performance over the entire range of mixture ratios (fluorine to oxygen, and oxidizer to fuel). The injector was 1 in. in diameter and delivered five pairs of 1:1 impinging fuel and oxidizer streams, the oxidizer being in the center of the chamber. The injector was so designed that the resultant momentum of the impinging streams was axial at a mixture ratio of 4.5 with 50 mole% fluorine. A double coil of 1/4-in. copper tubing (water-cooled) was installed 2 in. from the face of the injector as a turbulence promotor. The main propellants were ignited by means of a starting flame of gaseous hydrogen and oxygen, which also served to bring the thrust chamber nearly to thermal equilibrium before introduction of the test propellants

3. Thrust was measured with a 300-lb force ring (Wiancko Company), the output being recorded on a Consolidated Engineering Corporation multichannel oscillograph. Calibration was accomplished immediately after each test by placing weights on a pulley system connected to the thrust stand. Chamber pressure was measured both by an electrical bourdon gauge (Wiancko Company) and a hydraulic system recording on a Republic pressure recorder. Water-coolant flows were measured by Taylor differential pressure transmitters and recorded on Republic pressure recorders. Propellant flows were measured by calibrated General Electric tachometers attached to the moving pistons by racks and pinions and recorded on Esterline-Angus recorders.

VI. TESTING PROCEDURE

A. PROPELLANT HANDLING

1. Sufficient gasoline for several tests was introduced directly into the fuel cylinder from a storage container which was kept tightly sealed except when a sample was being withdrawn.

2. Mixtures of fluorine and oxygen were made by using a partially empty fluorine cylinder as a mixing chamber. This cylinder was connected by the proper tubing and fittings to a full cylinder of fluorine, which was then opened by remote control until a predetermined pressure of the gas was admitted to the mixing cylinder. After thermal equilibrium was established, the pressure in the mixing cylinder was carefully read. Oxygen was added in a like manner to the mixing cylinder; after thermal equilibrium was reached, the total pressure of the cylinder was carefully read. From these data the mole % of each of the two gases could be calculated. Ideal gas behavior was assumed in the calculations. At least two tests could be made from the same cylinder of mixed oxidizer. The limiting factor in mixing a large quantity of a given percentage of fluorine in oxygen was the pressure safety limit on the fluorine cylinder used for mixing. The mixed fluorine and oxygen gases were permitted to stand for at least 24 hr before being used and often for two or three days to ensure homogeneity.

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B. PRE-TEST CONDITIONING

1. Immediately before each test firing, relatively large quantities of the mixed oxidizer were bled through all sections of the motor with which fluorine would come in contact during the run. Bleeding was accomplished by first permitting nitrogen to flow through the system and then slowly adding the mixed oxidizer to this stream, decreasing the amount of nitrogen until the oxidizer alone was flowing. In this manner, any possible contaminants in the lines were slowly burned out. As a further precaution, the thrust chamber and injector components were thoroughly washed in detergent, rinsed with water, and blown dry with nitrogen before this conditioning treatment.

2. After the gaseous mixed oxidizer had been permitted to flow from the storage coil vent (see Figure 1), the vent valve was closed by remote control and liquid nitrogen was introduced into the coolant vessel surrounding the coil. At the same time the oxidizer cylinder on the test engine was filled with liquid nitrogen; the liquefied oxidizer and the liquid nitrogen used for displacement were separated by a valve which was opened only seconds before the opening of the main propellant valve. The mixed oxidizer was permitted to condense until a constant pressure reading was obtained, indicating that the storage coil was full.

C. MOTOR TEST

1. The motor was fired by placing a high-voltage ignition wire in the nozzle, closing the firing switch, and simultaneously opening the gaseous hydrogen and oxygen valves. During this portion of the test run, nitrogen bleeds were automatically maintained through both the fuel and oxidizer sides of the main injector so that no water could condense in the passages. Six to twelve sec after ignition of the hydrogen-oxygen flame, the valve separating the liquid nitrogen from the liquid fluorine was opened. The main propellant valves were then opened simultaneously, permitting the previously pressurized pistons to displace the liquids through the injector. The hydrogen-oxygen flame was shut off as soon as ignition of the test propellants occurred. The run was terminated when all of the mixed oxidizer had been displaced from the coil and liquid nitrogen entered the injector. The fuel valve was then closed, and the chamber was purged with high-pressure nitrogen.

2. The thrust unit was calibrated as soon as any fumes not absorbed by a sodium hydroxide spray tower had been exhausted from the test bay. At this time the diameter of the nozzle was determined, and the absorption tower wash water was examined for unburned carbon.

VII. RESULTS AND DISCUSSION

A. A total of 25 tests were made with oxidizer mixtures containing 0, 33, 50, 67, and 100 mole% fluorine. Maximum performance values were obtained with the 33% mixture; the specific impulse was 272 lb-sec/lb and the characteristic exhaust velocity was 6720 ft/sec. Performance increased from the 0%

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to the 33% mixture, decreased from this maximum with the 50% mixture, and then increased somewhat for the 67% mixture. No data were obtained with 100% fluorine because the two tests made with pure fluorine resulted in the only damage to the motor during the series.

B. Complete data for the tests are presented in Table I, and in graphical form in Figures 2, 3, and 4. A summary of the results previously obtained (Ref. 1) is shown as Table II. Both uncorrected and corrected values for heat loss to the coolant are presented in Figures 2 and 3, with tie-lines joining the values. Comparison of the two sets of results shows that the maximum performance values were obtained under widely different conditions. It is believed that the difference is due to the injectors used, each having been designed for different flow conditions. Extensive studies of the effect of injector configuration on performance, when fluorine is used as the oxidizer, have been made by NACA (Ref. 2 and 4). It was concluded that despite the high chemical reactivity of fluorine, it is necessary to conduct tests with a variety of injectors in order to obtain maximum performance. Not only do some injectors give a consistently lower percentage of theoretical performance than others, but some actually give relatively high performance over a very narrow range of mixture ratios, the performance then dropping off rapidly on either side of this peak. Such might be the case in the two series of tests made at Aerojet; the fact that the plot of maximum performance of the several mixtures is an "S"-shaped curve (increasing from 0% fluorine to 33%, declining from 33% to 50%, and then rising to 67%) could also be explained by the assumption that the injector used is capable of producing high performance only under certain restricted conditions of flow. A curve of this shape would be produced if maximum theoretical performance increased with percentage fluorine in the oxidizer (or even dropped off slightly as 100% fluorine is approached) and injector efficiency was low at approximately 50% fluorine, increasing on either side of this point.

In any event, it has been shown that with the proper injector, high values of specific impulse may be obtained when fluorine is diluted as much as two-thirds with oxygen. Even higher values might be possible if an injector study were undertaken.

C. Only two tests resulted in damage to the test engine. Both were tests in which 100% fluorine was used as the oxidizer. The first, Test No. D-45-LF-5, resulted in a fire that destroyed part of the injector oxidizer line and all of the injector face, and damaged the turbulator. The fire started as soon as the main propellant valve was opened, and must be attributed to some contaminant in the injector system. Figure 5 shows the extent of the damage. The second test, No. D-45-LF-25, resulted in more damage in the thrust chamber than did the first, but the primary cause of the fire was not the high reactivity of fluorine. The coolant water for the turbulator is supplied from a tank pressurized to 600 psi; the fact that coolant is flowing is verified before each test. Oscillograph records of the coolant water temperature show that the copper coils were heated far more than normally during

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the hydrogen-oxygen phase of the test, and that when the main propellants were introduced the water flow was not great enough to cool the turbulator properly. The entire turbulator was consumed, and part of one outside fitting and part of the nozzle was damaged; the injector system was not affected. The coolant filter was examined to determine whether solid particles might have restricted the water flow, but no obstructions could be found. The regulator supplying the high-pressure gas to the coolant supply was also examined to determine whether it might have failed to maintain the necessary pressure during the test, but no evidence of mechanical failure was found.

D. The wash water from the absorption tower for exhaust products was examined after each run for unburned carbon. Each of the tests made at 67% fluorine produced appreciable carbon, and the tests at 50% fluorine yielded much less, though some, carbon. No unburned carbon was found after any of the other tests. The exhaust flame was extremely bright in most of the tests, and bushy in appearance. Shock cones were often visible, but the flame was never sharp enough for the shock cones to be seen throughout the test.

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2. Research Memorandum E53E08, National Advisory Committee for Aeronautics, 3 July 1953 (Confidential).
3. Aerojet Report No. 527, 31 July 1951 (Confidential).
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lb/sec	W ₂₆₈ , lb/sec	W ₂₆₉ , lb/sec	W ₂₇₀ , lb/sec	W ₂₇₁ , lb/sec	W ₂₇₂ , lb/sec	W ₂₇₃ , lb/sec	W ₂₇₄ , lb/sec	W ₂₇₅ , lb/sec	W ₂₇₆ , lb/sec	W ₂₇₇ , lb/sec	W ₂₇₈ , lb/sec	W ₂₇₉ , lb/sec	W ₂₈₀ , lb/sec	W ₂₈₁ , lb/sec	W ₂₈₂ , lb/sec	W ₂₈₃ , lb/sec	W ₂₈₄ , lb/sec	W ₂₈₅ , lb/sec	W ₂₈₆ , lb/sec	W ₂₈₇ , lb/sec	W ₂₈₈ , lb/sec	W ₂₈₉ , lb/sec	W ₂₉₀ , lb/sec	W ₂₉₁ , lb/sec	W ₂₉₂ , lb/sec	W ₂₉₃ , lb/sec	W ₂₉₄ , lb/sec	W ₂₉₅ , lb/sec	W ₂₉₆ , lb/sec	W ₂₉₇ , lb/sec	W ₂₉₈ , lb/sec	W ₂₉₉ , lb/sec	W ₃₀₀ , lb/sec	W ₃₀₁ , lb/sec	W ₃₀₂ , lb/sec	W ₃₀₃ , lb/sec	W ₃₀₄ , lb/sec	W ₃₀₅ , lb/sec	W ₃₀₆ , lb/sec	W ₃₀₇ , lb/sec	W ₃₀₈ , lb/sec	W ₃₀₉ , lb/sec	W ₃₁₀ , lb/sec	W ₃₁₁ , lb/sec	W ₃₁₂ , lb/sec	W ₃₁₃ , lb/sec	W ₃₁₄ , lb/sec	W ₃₁₅ , lb/sec	W ₃₁₆ , lb/sec	W ₃₁₇ , lb/sec	W ₃₁₈ , lb/sec	W ₃₁₉ , lb/sec	W ₃₂₀ , lb/sec	W ₃₂₁ , lb/sec	W ₃₂₂ , lb/sec	W ₃₂₃ , lb/sec	W ₃₂₄ , lb/sec	W ₃₂₅ , lb/sec	W ₃₂₆ , lb/sec	W ₃₂₇ , lb/sec	W ₃₂₈ , lb/sec	W ₃₂₉ , lb/sec	W ₃₃₀ , lb/sec	W ₃₃₁ , lb/sec	W ₃₃₂ , lb/sec	W ₃₃₃ , lb/sec	W ₃₃₄ , lb/sec	W ₃₃₅ , lb/sec	W ₃₃₆ , lb/sec	W ₃₃₇ , lb/sec	W ₃₃₈ , lb/sec	W ₃₃₉ , lb/sec	W ₃₄₀ , lb/sec	W ₃₄₁ , lb/sec	W ₃₄₂ , lb/sec	W ₃₄₃ , lb/sec	W ₃₄₄ , lb/sec	W ₃₄₅ , lb/sec	W ₃₄₆ , lb/sec	W ₃₄₇ , lb/sec	W ₃₄₈ , lb/sec	W ₃₄₉ , lb/sec	W ₃₅₀ , lb/sec	W ₃₅₁ , lb/sec	W ₃₅₂ , lb/sec	W ₃₅₃ , lb/sec	W ₃₅₄ , lb/sec	W ₃₅₅ , lb/sec	W ₃₅₆ , lb/sec	W ₃₅₇ , lb/sec	W ₃₅₈ , lb/sec	W ₃₅₉ , lb/sec	W ₃₆₀ , lb/sec	W ₃₆₁ , lb/sec	W ₃₆₂ , lb/sec	W ₃₆₃ , lb/sec	W ₃₆₄ , lb/sec	W ₃₆₅ , lb/sec	W ₃₆₆ , lb/sec	W ₃₆₇ , lb/sec	W ₃₆₈ , lb/sec	W ₃₆₉ , lb/sec	W ₃₇₀ , lb/sec	W ₃₇₁ , lb/sec	W ₃₇₂ , lb/sec	W ₃₇₃ , lb/sec	W ₃₇₄ , lb/sec	W ₃₇₅ , lb/sec	W ₃₇₆ , lb/sec	W ₃₇₇ , lb/sec	W ₃₇₈ , lb/sec	W ₃₇₉ , lb/sec	W ₃₈₀ , lb/sec	W ₃₈₁ , lb/sec	W ₃₈₂ , lb/sec	W ₃₈₃ , lb/sec	W ₃₈₄ , lb/sec	W ₃₈₅ , lb/sec	W ₃₈₆ , lb/sec	W ₃₈₇ , lb/sec	W ₃₈₈ , lb/sec	W ₃₈₉ , lb/sec	W ₃₉₀ , lb/sec	W ₃₉₁ , lb/sec	W ₃₉₂ , lb/sec	W ₃₉₃ , lb/sec	W ₃₉₄ , lb/sec	W ₃₉₅ , lb/sec	W ₃₉₆ , lb/sec	W ₃₉₇ , lb/sec	W ₃₉₈ , lb/sec	W ₃₉₉ , lb/sec	W ₄₀₀ , lb/sec	W ₄₀₁ , lb/sec	W ₄₀₂ , lb/sec	W ₄₀₃ , lb/sec	W ₄₀₄ , lb/sec	W ₄₀₅ , lb/sec	W ₄₀₆ , lb/sec	W ₄₀₇ , lb/sec	W ₄₀₈ , lb/sec	W ₄₀₉ , lb/sec	W ₄₁₀ , lb/sec	W ₄₁₁ , lb/sec	W ₄₁₂ , lb/sec	W ₄₁₃ , lb/sec	W ₄₁₄ , lb/sec	W ₄₁₅ , lb/sec	W ₄₁₆ , lb/sec	W ₄₁₇ , lb/sec	W ₄₁₈ , lb/sec	W ₄₁₉ , lb/sec	W ₄₂₀ , lb/sec	W ₄₂₁ , lb/sec	W ₄₂₂ , lb/sec	W ₄₂₃ , lb/sec	W ₄₂₄ , lb/sec	W ₄₂₅ , lb/sec	W ₄₂₆ , lb/sec	W ₄₂₇ , lb/sec	W ₄₂₈ , lb/sec	W ₄₂₉ , lb/sec	W ₄₃₀ , lb/sec	W ₄₃₁ , lb/sec	W ₄₃₂ , lb/sec	W ₄₃₃ , lb/sec	W ₄₃₄ , lb/sec	W ₄₃₅ , lb/sec	W ₄₃₆ , lb/sec	W ₄₃₇ , lb/sec	W ₄₃₈ , lb/sec	W ₄₃₉ , lb/sec	W ₄₄₀ , lb/sec	W ₄₄₁ , lb/sec	W ₄₄₂ , lb/sec	W ₄₄₃ , lb/sec	W ₄₄₄ , lb/sec	W ₄₄₅ , lb/sec	W ₄₄₆ , lb/sec	W ₄₄₇ , lb/sec	W ₄₄₈ , lb/sec	W ₄₄₉ , lb/sec	W ₄₅₀ , lb/sec	W ₄₅₁ , lb/sec	W ₄₅₂ , lb/sec	W ₄₅₃ , lb/sec	W ₄₅₄ , lb/sec	W ₄₅₅ , lb/sec	W ₄₅₆ , lb/sec	W ₄₅₇ , lb/sec	W ₄₅₈ , lb/sec	W ₄₅₉ , lb/sec	W ₄₆₀ , lb/sec	W ₄₆₁ , lb/sec	W ₄₆₂ , lb/sec	W ₄₆₃ , lb/sec	W ₄₆₄ , lb/sec	W ₄₆₅ , lb/sec	W ₄₆₆ , lb/sec	W ₄₆₇ , lb/sec	W ₄₆₈ , lb/sec	W ₄₆₉ , lb/sec	W ₄₇₀ , lb/sec	W ₄₇₁ , lb/sec	W ₄₇₂ , lb/sec	W ₄₇₃ , lb/sec	W ₄₇₄ , lb/sec	W ₄₇₅ , lb/sec	W ₄₇₆ , lb/sec	W ₄₇₇ , lb/sec	W ₄₇₈ , lb/sec	W ₄₇₉ , lb/sec	W ₄₈₀ , lb/sec	W ₄₈₁ , lb/sec	W ₄₈₂ , lb/sec	W ₄₈₃ , lb/sec	W ₄₈₄ , lb/sec	W ₄₈₅ , lb/sec	W ₄₈₆ , lb/sec	W ₄₈₇ , lb/sec	W ₄₈₈ , lb/sec	W ₄₈₉ , lb/sec	W ₄₉₀ , lb/sec	W ₄₉₁ , lb/sec	W ₄₉₂ , lb/sec	W ₄₉₃ , lb/sec	W ₄₉₄ , lb/sec	W ₄₉₅ , lb/sec	W ₄₉₆ , lb/sec	W ₄₉₇ , lb/sec	W ₄₉₈ , lb/sec	W ₄₉₉ , lb/sec	W ₅₀₀ , lb/sec	W ₅₀₁ , lb/sec	W ₅₀₂ , lb/sec	W ₅₀₃ , lb/sec	W ₅₀₄ , lb/sec	W ₅₀₅ , lb/sec	W ₅₀₆ , lb/sec	W ₅₀₇ , lb/sec	W ₅₀₈ , lb/sec	W ₅₀₉ , lb/sec	W ₅₁₀ , lb/sec	W ₅₁₁ , lb/sec	W ₅₁₂ , lb/sec	W ₅₁₃ , lb/sec	W ₅₁₄ , lb/sec	W ₅₁₅ , lb/sec	W ₅₁₆ , lb/sec	W ₅₁₇ , lb/sec	W ₅₁₈ , lb/sec	W ₅₁₉ , lb/sec	W ₅₂₀ , lb/sec	W ₅₂₁ , lb/sec	W ₅₂₂ , lb/sec	W ₅₂₃ , lb/sec	W ₅₂₄ , lb/sec	W ₅₂₅ , lb/sec	W ₅₂₆ , lb/sec	W ₅₂₇ , lb/sec	W ₅₂₈ , lb/sec	W ₅₂₉ , lb/sec	W ₅₃₀ , lb/sec	W ₅₃₁ , lb/sec	W ₅₃₂ , lb/sec	W ₅₃₃ , lb/sec	W ₅₃₄ , lb/sec	W ₅₃₅ , lb/sec	W ₅₃₆ , lb/sec	W ₅₃₇ , lb/sec	W ₅₃₈ , lb/sec	W ₅₃₉ , lb/sec	W ₅₄₀ , lb/sec	W ₅₄₁ , lb/sec	W ₅₄₂ , lb/sec	W ₅₄₃ , lb/sec	W ₅₄₄ , lb/sec	W ₅₄₅ , lb/sec	W ₅₄₆ , lb/sec	W ₅₄₇ , lb/sec	W ₅₄₈ , lb/sec	W ₅₄₉ , lb/sec	W ₅₅₀ , lb/sec	W ₅₅₁ , lb/sec	W ₅₅₂ , lb/sec	W ₅₅₃ , lb/sec	W ₅₅₄ , lb/sec	W ₅₅₅ , lb/sec	W ₅₅₆ , lb/sec	W ₅₅₇ , lb/sec	W ₅₅₈ , lb/sec	W ₅₅₉ , lb/sec	W ₅₆₀ , lb/sec	W ₅₆₁ , lb/sec	W ₅₆₂ , lb/sec	W ₅₆₃ , lb/sec	W ₅₆₄ , lb/sec	W ₅₆₅ , lb/sec	W ₅₆₆ , lb/sec	W ₅₆₇ , lb/sec	W ₅₆₈ , lb/sec	W ₅₆₉ , lb/sec	W ₅₇₀ , lb/sec	W ₅₇₁ , lb/sec	W ₅₇₂ , lb/sec	W ₅₇₃ , lb/sec	W ₅₇₄ , lb/sec	W ₅₇₅ , lb/sec	W ₅₇₆ , lb/sec	W ₅₇₇ , lb/sec	W ₅₇₈ , lb/sec	W ₅₇₉ , lb/sec	W ₅₈₀ , lb/sec	W ₅₈₁ , lb/sec	W ₅₈₂ , lb/sec	W ₅₈₃ , lb/sec	W ₅₈₄ , lb/sec	W ₅₈₅ , lb/sec	W ₅₈₆ , lb/sec	W ₅₈₇ , lb/sec	W ₅₈₈ , lb/sec	W ₅₈₉ , lb/sec	W ₅₉₀ , lb/sec	W ₅₉₁ , lb/sec	W ₅₉₂ , lb/sec	W ₅₉₃ , lb/sec	W ₅₉₄ , lb/sec	W ₅₉₅ , lb/sec	W ₅₉₆ , lb/sec	W ₅₉₇ , lb/sec	W ₅₉₈ , lb/sec	W ₅₉₉ , lb/sec	W ₆₀₀ , lb/sec	W ₆₀₁ , lb/sec	W ₆₀₂ , lb/sec	W ₆₀₃ , lb/sec	W ₆₀₄ , lb/sec	W ₆₀₅ , lb/sec	W ₆₀₆ , lb/sec	W ₆₀₇ , lb/sec	W ₆₀₈ , lb/sec	W ₆₀₉ , lb/sec	W ₆₁₀ , lb/sec	W ₆₁₁ , lb/sec	W ₆₁₂ , lb/sec	W ₆₁₃ , lb/sec	W ₆₁₄ , lb/sec	W ₆₁₅ , lb/sec	W ₆₁₆ , lb/sec	W ₆₁₇ , lb/sec	W ₆₁₈ , lb/sec	W ₆₁₉ , lb/sec	W ₆₂₀ , lb/sec	W ₆₂₁ , lb/sec	W ₆₂₂ , lb/sec	W ₆₂₃ , lb/sec	W ₆₂₄ , lb/sec	W ₆₂₅ , lb/sec	W ₆₂₆ , lb/sec	W ₆₂₇ , lb/sec	W ₆₂₈ , lb/sec	W ₆₂₉ , lb/sec	W ₆₃₀ , lb/sec	W ₆₃₁ , lb/sec	W ₆₃₂ , lb/sec	W ₆₃₃ , lb/sec	W ₆₃₄ , lb/sec	W ₆₃₅ , lb/sec	W ₆₃₆ , lb/sec	W ₆₃₇ , lb/sec	W ₆₃₈ , lb/sec	W ₆₃₉ , lb/sec	W ₆₄₀ , lb/sec	W ₆₄₁ , lb/sec	W ₆₄₂ , lb/sec	W ₆₄₃ , lb/sec	W ₆₄₄ , lb/sec	W ₆₄₅ , lb/sec	W ₆₄₆ , lb/sec	W ₆₄₇ , lb/sec	W ₆₄₈ , lb/sec	W ₆₄₉ , lb/sec	W ₆₅₀ , lb/sec	W ₆₅₁ , lb/sec	W ₆₅₂ , lb/sec	W ₆₅₃ , lb/sec	W ₆₅₄ , lb/sec	W ₆₅₅ , lb/sec	W ₆₅₆ , lb/sec	W ₆₅₇ , lb/sec	W ₆₅₈ , lb/sec	W ₆₅₉ , lb/sec	W ₆₆₀ , lb/sec	W ₆₆₁ , lb/sec	W ₆₆₂ , lb/sec	W ₆₆₃ , lb/sec	W ₆₆₄ , lb/sec	W ₆₆₅ , lb/sec	W ₆₆₆ , lb/sec	W ₆₆₇ , lb/sec	W ₆₆₈ , lb/sec	W ₆₆₉ , lb/sec	W ₆₇₀ , lb/sec	W ₆₇₁ , lb/sec	W ₆₇₂ , lb/sec	W ₆₇₃ , lb/sec	W ₆₇₄ , lb/sec	W ₆₇₅ , lb/sec	W ₆₇₆ , lb/sec	W ₆₇₇ , lb/sec	W ₆₇₈ , lb/sec	W ₆₇₉ , lb/sec	W ₆₈₀ , lb/sec	W ₆₈₁ , lb/sec	W ₆₈₂ , lb/sec	W ₆₈₃ , lb/sec	W ₆₈₄ , lb/sec	W ₆₈₅ , lb/sec	W ₆₈₆ , lb/sec	W ₆₈₇ , lb/sec	W ₆₈₈ , lb/sec	W ₆₈₉ , lb/sec	W ₆₉₀ , lb/sec	W ₆₉₁ , lb/sec	W ₆₉₂ , lb/sec	W ₆₉₃ , lb/sec	W ₆₉₄ , lb/sec	W ₆₉₅ , lb/sec	W ₆₉₆ , lb/sec	W ₆₉₇ , lb/sec	W ₆₉₈ , lb/sec	W ₆₉₉ , lb/sec	W ₇₀₀ , lb/sec	W ₇₀₁ , lb/sec	W ₇₀₂ , lb/sec	W ₇₀₃ , lb/sec	W ₇₀₄ , lb/sec	W ₇₀₅ , lb/sec	W ₇₀₆ , lb/sec	W ₇₀₇ , lb/sec	W ₇₀₈ , lb/sec	W ₇₀₉ , lb/sec	W ₇₁₀ , lb/sec	W ₇₁₁ , lb/sec	W ₇₁₂ , lb/sec	W ₇₁₃ , lb/sec	W ₇₁₄ , lb/sec	W ₇₁₅ , lb/sec	W ₇₁₆ , lb/sec	W ₇₁₇ , lb/sec	W ₇₁₈ , lb/sec	W ₇₁₉ , lb/sec	W ₇₂₀ , lb/sec	W ₇₂₁ , lb/sec	W _{722</}

CONFIDENTIAL

Report No. 763

TABLE II

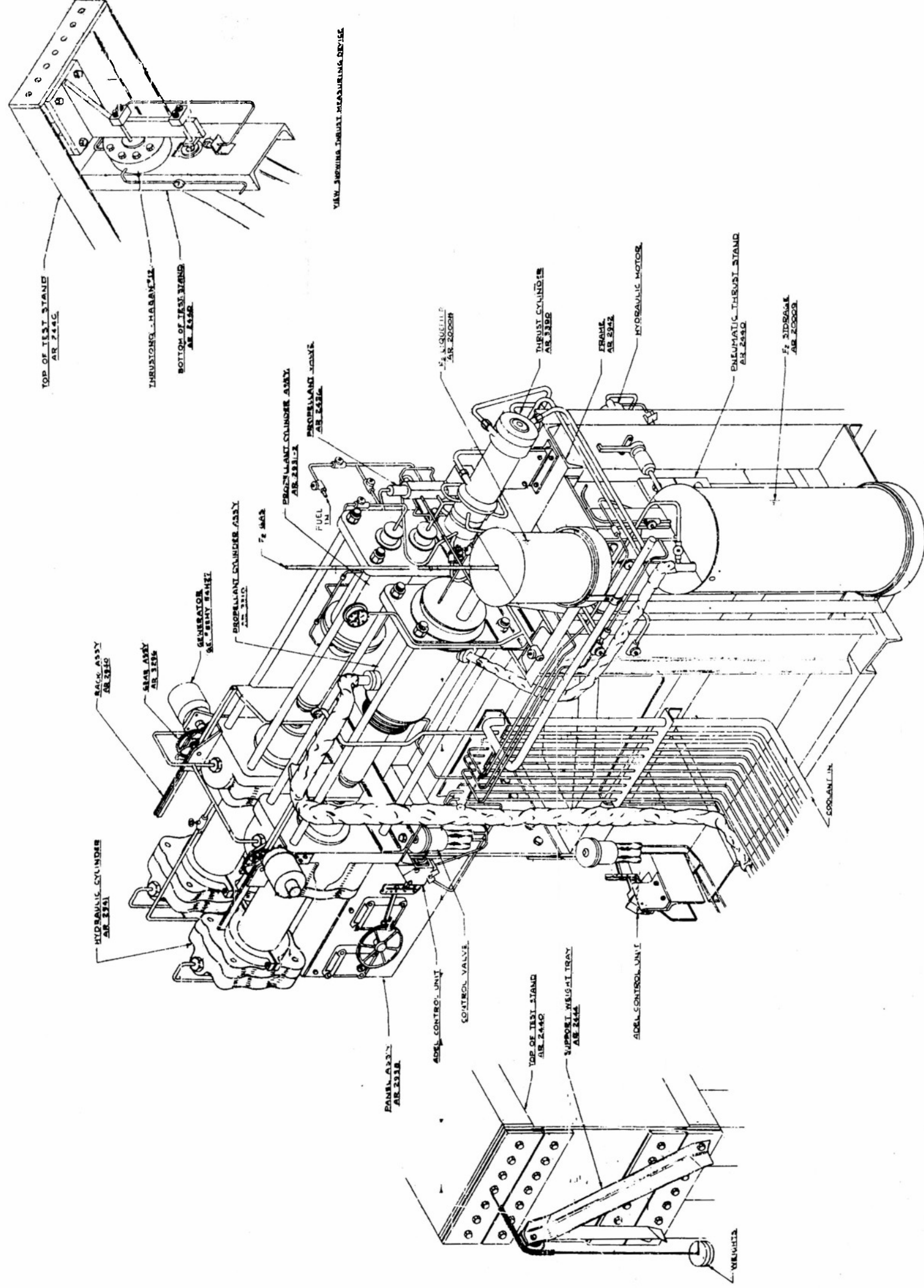
AVIATION GASOLINE AND MIXTURES OF LIQUID FLUORINE AND LIQUID OXYGEN

SUMMARY OF PERFORMANCE DATA

Test No. PP-15-1-	Fuel	Oxidizer				Chamber Pressure psia	M.R. (w_{ox}/w_f)	Cp (Corr. for Heat-Trans.)	Isp (Uncorr.) lb-sec/lb	*, ft/sec (Corr. for Heat-Trans.)	Isp, lb-sec/lb, (Corr. for Heat-Trans.)	Molar Mixture Ratio
		Mole%		Wt%								
		F ₂	O ₂	F ₂	O ₂							
1	Aviation Gasoline	50.7	49.3	55.0	45.0	225	2.57	1.34	192	4708	196	8.29
2		50.7	49.3	55.0	45.0	330	3.82	1.46	244	5541	252	12.32
3		—	100	—	100	241	2.51	1.32	198	5016	206	8.86
4		50.3	49.7	54.6	45.4	319	5.85	1.43	242	5665	252	18.88
5		50.3	49.7	54.6	45.4	322	4.62	1.43	253	5884	261	14.91
6		50.3	49.7	54.6	45.4	316	4.87	1.43	243	5736	255	15.72
7		66.7	33.3	70.4	29.6	321	4.62	1.41	247	5991	262	14.50
8		66.7	33.3	70.4	29.6	305	3.87	1.42	237	5648	249	12.15

Table II

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1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98	99	100
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Report No. 763

C-3441 EMH:JF 9-10-53

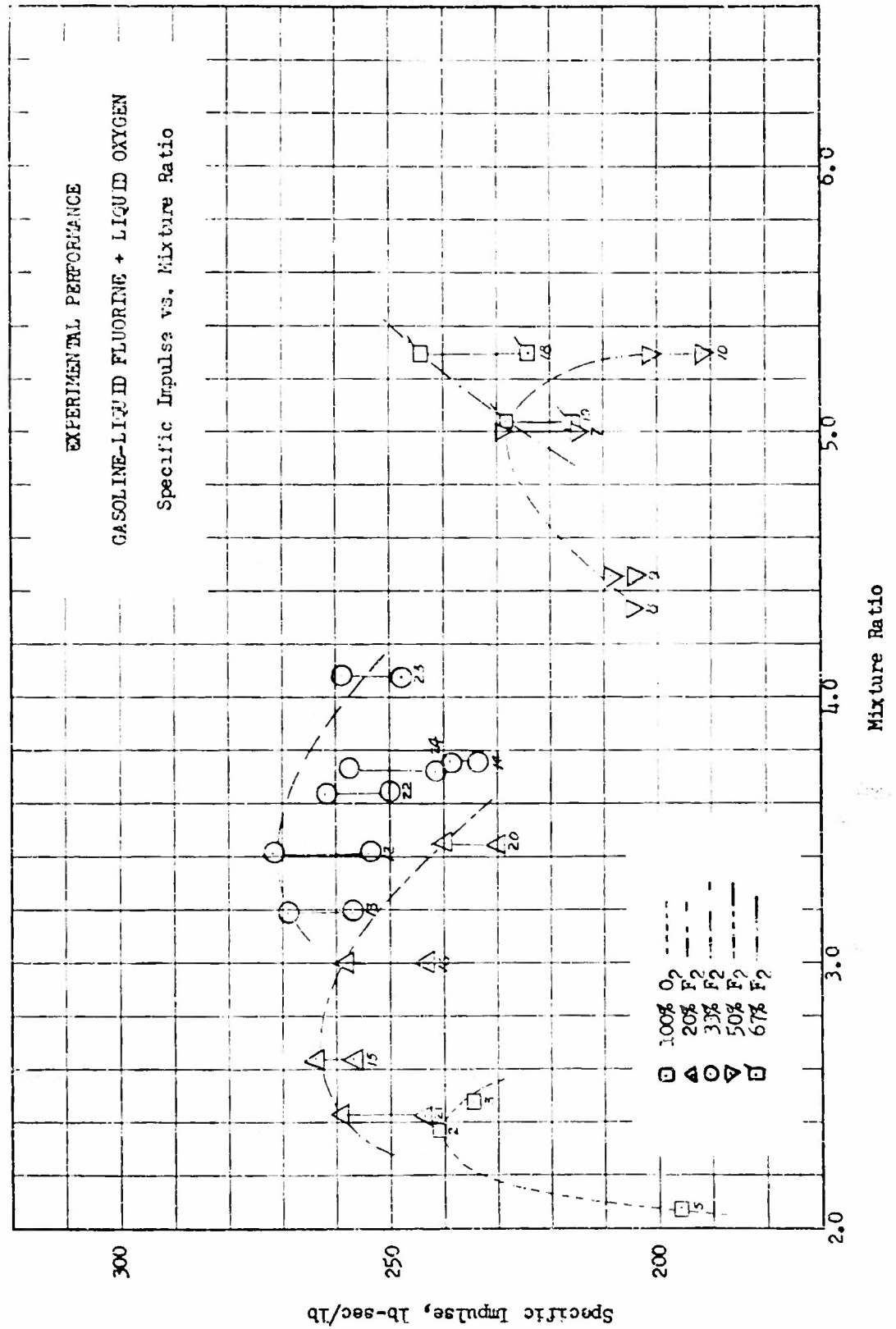


Figure 2

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Report No. 763

C- 3439 EMM:lft 9-10-53

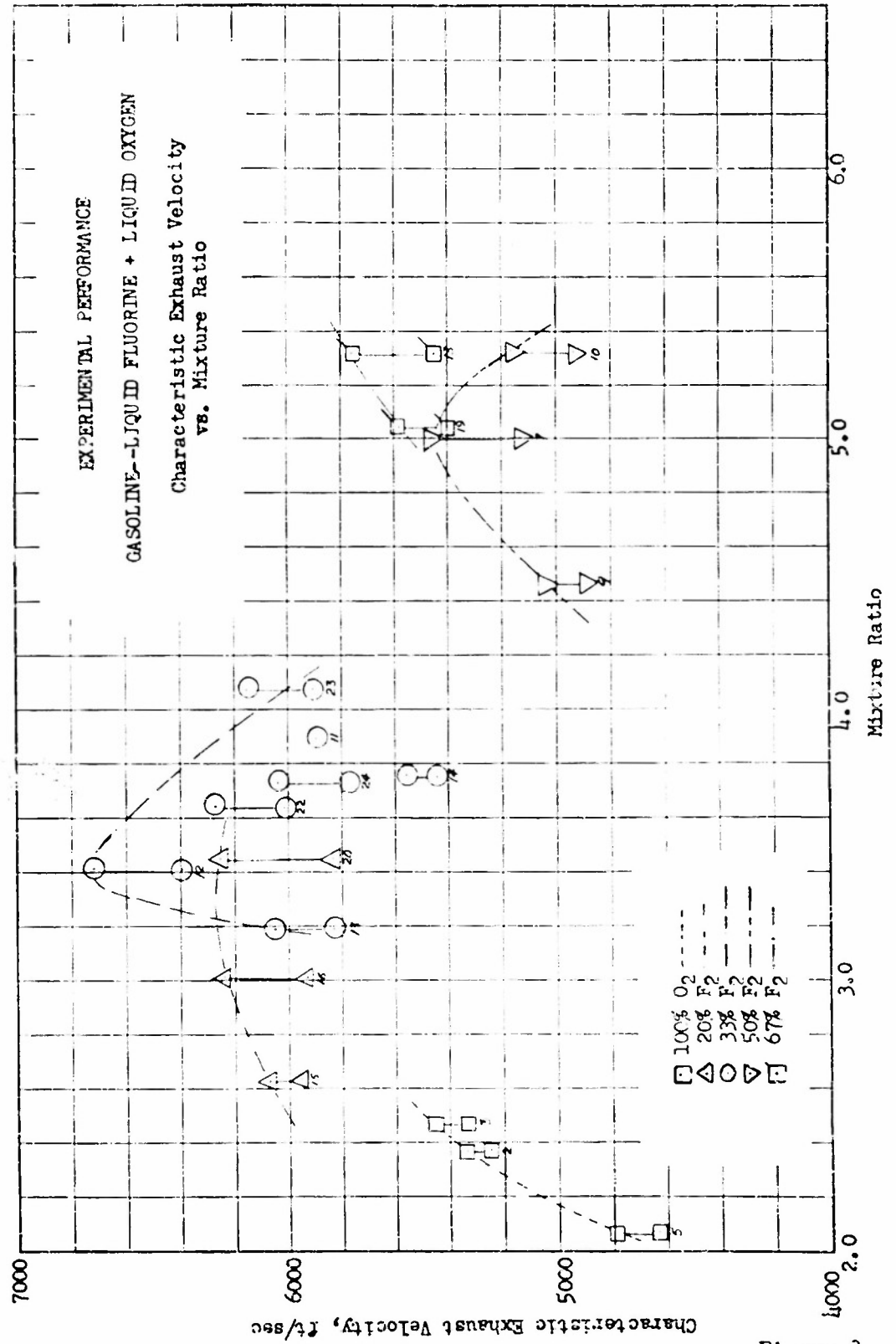


Figure 3

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C-3440 EMW:171 9-10-53

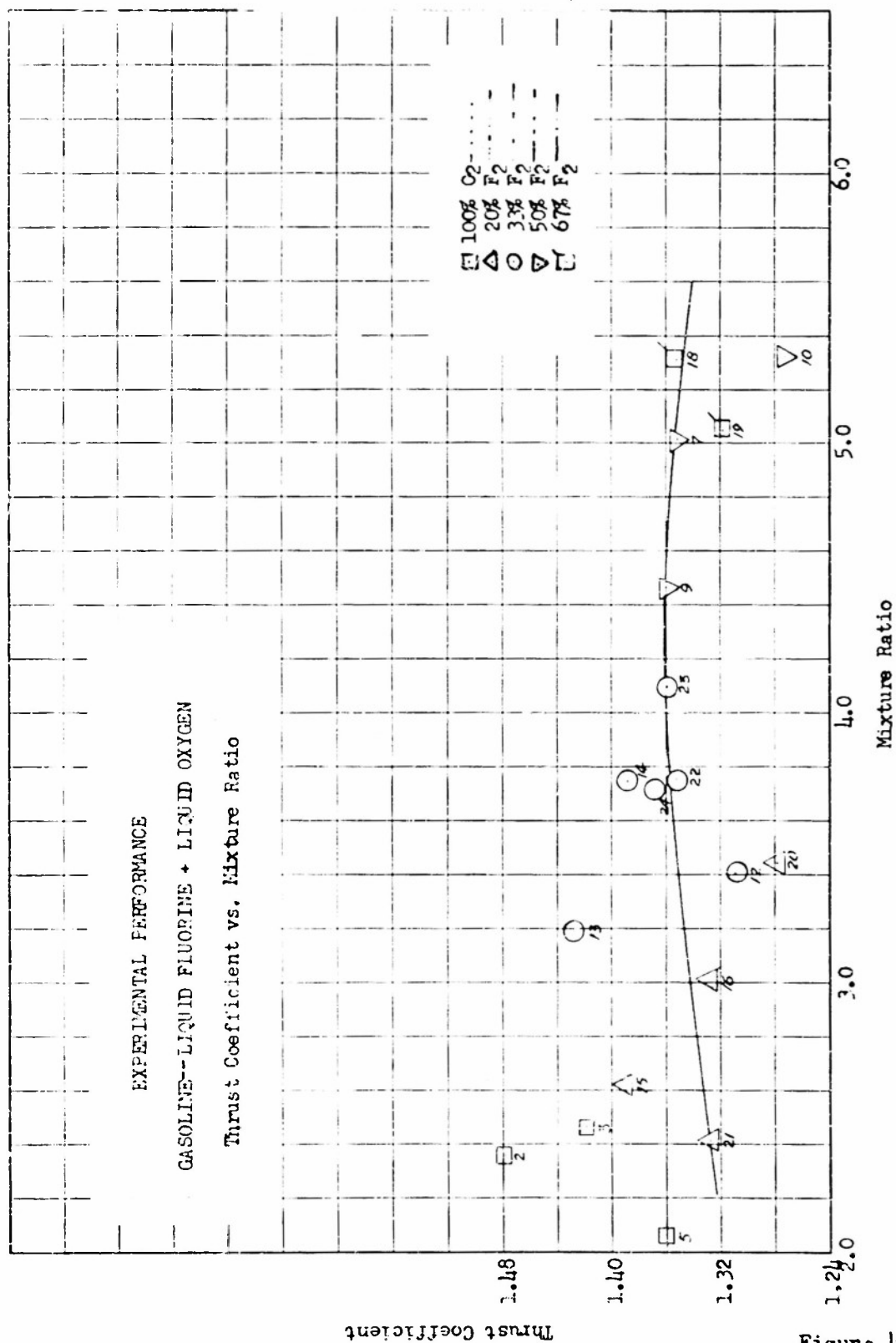


Figure 1



Damage to Injector System During Test D-45-LF-5

0653-610

Figure 5